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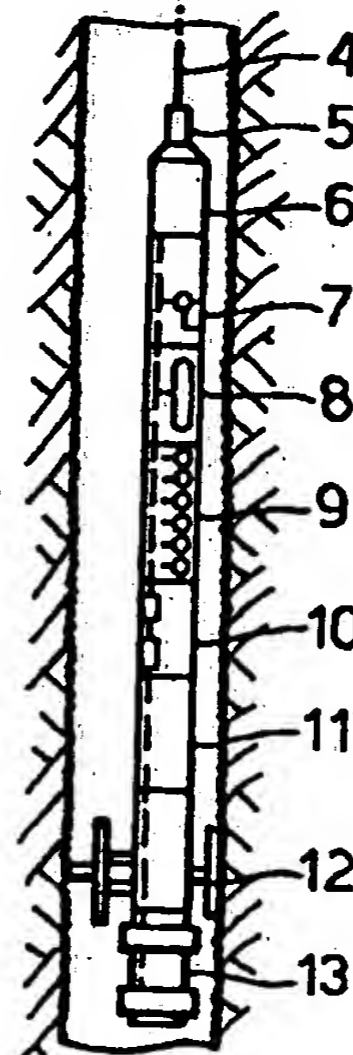
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(54) Title: DOWNHOLE TOOL SYSTEM

(57) Abstract

A downhole tool system which comprises a downhole tool connected for fluid communication to a continuous reel of tubing (1), drill pipe or conventional tubing via a pressure-tight connector (5) for flowing fluids between the formation, the tool and the surface, the downhole tool being in electrical communication with the surface (4).



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- 1 -

**DOWNHOLE TOOL SYSTEM**

This invention relates to the evaluation of reservoir properties and well intervention in oil and gas wells.

Traditional well evaluation, to evaluate reservoir or  
5 well properties, relies on many well-known tools, generally referred to as downhole tools, which include electrical wireline logs and drill stem test (DST) equipment.

Electrical wireline tools are lowered into the borehole on an armoured, wound steel cable which contains one or several  
10 electrical wires to carry power, data and control signals. Using acoustic, nuclear, gamma ray, conductivity and other physical principles, these tools can provide, for example, information on porosity, water saturation and clay content of the rock formations. There are also tools known as Wireline  
15 Fluid Samplers (WFS) which can obtain reservoir pressure and temperature data and can obtain downhole samples of reservoir fluids.

DST equipment is lowered into the borehole to flow a well (producing fluid from the reservoir, usually to surface), and  
20 it is run on drillpipe or tubing. These tools are operated to flow, shut-in or circulate the well either by mechanical manipulation of the drillpipe or by annulus pressure (the pressure in the annulus between the liner and the drillpipe). The typical DST is a short-term flow test which can last a few  
25 hours to a few days. It usually includes fluid sampling and measurement of the recovery of reservoir pressure after the flow period, since this can provide important reservoir information.

Well intervention, to enhance oil or gas production or  
30 reduce water production, can be carried out in several ways. Coiled tubing has been used increasingly for this purpose for many years. It is a service provided by many companies including Halliburton, Nowsco and Schlumberger Dowell. Coiled tubing is typically manufactured from stainless steel. It can  
35 be seam-welded into lengths of 1,000m or more. It can be butt-welded to create longer lengths. It was originally available in small sizes of about 25.4mm diameter, but larger sizes, which can be about 60.3mm diameter or larger, are now available. It is flexible enough to be wound onto a large reel which

- 2 -

typically contains lengths of over 3000m. The coiled tubing can be manoeuvred into or out of the well by means of an injector. The coiled tubing can be gripped by contoured blocks which are carried on 2 sets of chains. It can be connected to the wellhead through a stuffing box and blow out preventer. The stuffing box allows the coiled tubing to be run into or out of the hole while under pressure.

Its small diameter enables the coiled tubing to be run inside a well completion tubing string (typically in the range 60.3 - 177.8 mm diameter, although smaller and larger tubings exist). Uses include, for example, nitrogen lifting a well (to initiate flow to surface) and for placing or injecting acids or other chemicals into the formation. Coiled tubing drilling is another type of well intervention. Using downhole turbine motors driven by the pumping of drilling fluids, solids or cement which have settled where they are not wanted can be drilled out.

The latest WFS tools include the Schlumberger Modular Formation Dynamics tester (MDT) and the Western Atlas Reservoir Characterisation Instrument (RCI). These have either a probe and seal module which presses against the borehole wall or a straddle packer module (2 packers which are a few feet apart) to seal a short section of the borehole. They can pump fluids from the formation into the wellbore, in order to draw uncontaminated formation fluids into the tool prior to taking representative samples. Electrical power for the pump is carried down the wireline cable, which also enables data telemetry. Wireline fluid samplers (WFS) offer cheaper ways to perform some operations traditionally done with DST tools - providing surface readout of downhole pressures and temperatures and capturing downhole hydrocarbon samples for laboratory analysis.

WFS tools are, however, limited in several ways. They cannot be used for injection of treatment fluids from surface. Also, the volume of hydrocarbon which can be pumped from the formation using a WFS is limited to at most a few barrels because there is a risk of creating a "kick". A "kick" is an influx of reservoir fluids into the wellbore, which, if not controlled, can quickly rise to surface and create a high

pressure surge. If not controlled, this surge can blow mud out of the hole which, if unchecked, can cause a blowout.

Hydrocarbons must be pumped to cleanup before taking a sample, otherwise the sample will be contaminated. A WFS can only pump  
5 fluids into the annulus (the annular space between the borehole wall and the WFS tool or its wireline cable). Such fluids are free to rise to surface, creating the risk of a kick.

WFS samples often suffer from contamination from drilling mud which can reduce the quality of the samples and introduce  
10 errors in phase behaviour predictions. This can be especially problematic when pseudo oil-based muds are used for drilling. These may contain some components which also occur in crude oils and so can lead to confusion. There are techniques, using equation of state simulation, to compensate for the impact of  
15 this contamination. However, it is advantageous to reduce the amount of contamination in the samples in the first place.

The latest coiled tubing applications include advanced drilling applications such as sidetracking to drill new wells - especially horizontal and multi-lateral wells. Other uses are  
20 to cut it and use it as a quicker and cheaper completion than small-sized conventional tubing. A completion is typically run to achieve permanent production from a well. It is typically a string of tubing, a packer which anchors and seals against the liner and various tubular sections with machined internal  
25 profiles to receive matching profiled plugs. Coiled tubing can also aid running electrical wireline logs in difficult conditions, such as high angle or horizontal wells. The downhole tools and electrical wireline cable can be pushed to the bottom of the well using the weight and stiffness of the  
30 coiled tubing. In more extreme situations, calling for even more weight and stiffness, drillpipe must be used, although this is a slower operation.

Coiled tubing can also have electrical wireline cable pumped through it to run its entire length. This helps to  
35 obtain a pressure seal (compared with running the electrical wireline cable outside the coiled tubing) when running downhole tools under pressure in a producing well. It can be used, for example, to run wireline production logs in high angle wells. These use temperature probes, gradiomanometers to measure fluid

- 4 -

density changes and turbine spinners to measure flowrate. Current uses of coiled tubing are therefore diverse. However, they do not exploit the capability to flow or pump hydrocarbons up the coiled tubing. Nor do they combine such flow with  
5 downhole electrical instrumentation and control.

The present invention is described here in broad concept. It is a downhole tool system and method which allows the previously separate operational capabilities and uses of DSTs, wireline, and coiled tubing to be combined to advantage. It is  
10 a downhole tool system which enables high quality sampling and many other forms of well evaluation and intervention. The downhole tool system uses coiled tubing, or a similar continuous reel of tubing, to run the downhole tool into a well. The downhole tool is run into the well and its packer or  
15 probe can be set and unset to seal against the borehole wall as often as required, using internal hydraulic power generated via the electrical power from surface. The method can be used to run the downhole tool into an "open hole" (before casing or liner has been run) or after completion, when a tubing string  
20 has been run and set to produce from the well. The method can be used advantageously in multi-lateral boreholes (multiple high deviation wellbores branching from one vertical wellbore).

The present invention provides a device which may be used in a sampling method in which the downhole sampling tool is run  
25 into the borehole on electrical coiled tubing (coiled tubing containing a wireline cable within it, running its entire length) or similar continuous reel of tubing which provides for electrical connection for power, control and data telemetry. The downhole tool of the invention could also be run on drill  
30 pipe or tubing in a similar way. In all cases, a connector with a pressure-tight seal is required, so that the downhole tool of the invention may pump safely into the coiled tubing or fluids may be pumped safely from surface down the coiled tubing and through the downhole tool. In the case where the downhole tool  
35 is connected to electrical coiled tubing with an internal wireline, the connector must provide a pressure-tight means for the wireline cable to exit through the flow tube to establish electrical contact with the tool electronics. In such a case, and unlike a WFS, which can only vent fluids to the side, the

- 5 -

flow tube will pass from the top, down the tool, either internally or externally.

Electrical termination at surface may be by a pressure-tight brush pickup in the coiled tubing reel. The electrical cable is used to transmit power and control signals to the downhole device and provides the means for data telemetry from the tool during operation. The method can be used to run the downhole tool either in "open hole" (before casing or liner has been run) or after completion, when a string of tubing has been permanently set in place to produce from the well.

The downhole tool may be of modular design, allowing the use of either a probe, single packer or straddle packer module, running internally carried sample bottles which are certified for air transport, running large sample containers, providing a pump module and providing various downhole sensors. For running inside small diameter completions, a small diameter "slim hole" version of the downhole tool is required.

The current invention can provide real-time surface readout of pressure, temperature and differentiation of fluid phases from each other such as through means of light absorption and by in-situ measurement of saturation pressure by de-pressurisation and re-pressurisation of a sample. The tool can be run in conjunction with downhole cameras, steering and traction devices to find and enter multiple boreholes.

A considerable advantage of the present invention is that it allows quicker evaluation than with a conventional DST. Being continuous, it is intrinsically quicker and safer to run into and pull out of the hole. Unlike DSTs, it does not require mechanical manipulation of the coiled tubing or the application of annulus pressure to operate, which often requires a liner to be run. A liner is expensive and the operation typically lasts several days, so avoiding it can offer a large cost-saving. Unlike a WFS, the downhole tool can receive fluids pumped from surface.

Furthermore, the present invention can pump or flow more fluids at higher rates from the reservoir than a WFS to increase the chances of gathering high quality samples. The present invention reduces the amount of contamination in samples by enabling much increased volumes of fluid to be

pumped or flowed before sampling takes place, thus enabling more complete cleanup to representative reservoir fluids. Preferably, the pump and internal tubing within the tool are larger than in WFS tools. This enables the larger cleanup  
5 volumes to be pumped at higher rates than in WFS tools, so that larger volumes can be handled reasonably quickly.

Evaluation or treatment of multiple zones is possible in one run in the hole and is relatively quick to perform, whereas usually this would require multiple runs with DST tools. Small  
10 zones can be precisely targeted if necessary, which can enable investigation of changes in reservoir or fluid properties over small distances or reduce injection treatment volumes. By using cameras, steering and traction devices, evaluation or treatment  
15 of each borehole in a multi-lateral well is possible in one run in the hole which again can save time.

A specific embodiment of the invention will now be described by way of example with reference to the accompanying drawings in which :

Figure 1 is a schematic side view of an electrical coiled  
20 tubing reel and injector assembly.

Figure 2 is a schematic side view of the downhole tool suspended in the well.

Figure 3 is a schematic cross section of one type of electrical coiled tubing containing an electrical wireline  
25 cable.

Figure 1 shows the electrical coiled tubing reel (1), injector assembly (2) and stuffing box (3) mounted over the wellhead with the electrical coiled tubing (4) run into the borehole. Figure 2 shows the downhole tool suspended in the  
30 well in open hole on the electrical coiled tubing (4). Figure 3 shows a cross section of the electrical coiled tubing (4) containing the electrical wireline (14).

Referring to the drawing, the downhole tool is connected to the coiled tubing via the connector (5). In open hole, the  
35 downhole tool can be positioned using a gamma ray or other depth reference (6) next to a zone of interest. The tool is set in position using hydraulic power to press the probe (12) packer or packers (13) into the borehole wall. The tool is run in drilling mud or kill-weight fluid. In the event of power

- 7 -

failure, a failsafe valve in the pump module (7) closes in the downhole tool to isolate the coiled tubing from the annulus. Retraction of the probe (12) is delayed by means of a hydraulic reservoir (10) to allow recovery from brief power outages without unsettling the tool.

The pump module (7) is used to pump fluid from the formation into the coiled tubing (4). By opening a valve, it can also pump into the annulus. A "cushion" of less dense fluid inside the coiled tubing is not necessary to control drawdown (pressure drop) on the formation, as it is in a DST, which can save time. Depending on the drawdown, the well may be able to flow naturally into the coiled tubing (4), in which case the pump can be by-passed by opening a by-pass valve. The contamination of the flowstream can be measured using downhole sensors (11) and monitored in real time via telemetry to surface. Flow can be sustained for as long as necessary to obtain high quality samples with real time indication of the fluid sample quality. The volume flowed is limited only by drawdown, pump capacity and time available. Once clean fluids are flowing, samples can be captured using the tools internal multi-sample bottles (9) or large sample chamber (8). The internal sample bottles (9) can be approved for air transport so that transfer into another vessel approved for transport is not required at surface, which can be detrimental to sample quality. If required, a pressure build up with downhole shut-in can be carried out. The tool can then be unset and moved on to a new zone of interest.

For running inside completions in cased hole, a slim hole version of the downhole tool can be set at specific depths with a gamma ray or casing collar locator. A packer or straddle packer module (13) is used to isolate the perforated zone of interest in order to inject or displace fluids, or to flow and take fully instrumented downhole samples from specific intervals.

During injection, downhole measurement and real time surface monitoring via telemetry enable confirmation that all the right fluids have been injected into the right place. During flow, the monitoring permits investigation of the fluids flowing before committing to a sample. If necessary, flow can

be sustained from a specific interval until it stabilises (measuring for example a water-oil ratio or gas-oil ratio) or until it reaches surface. If the interval being tested dies due to unloading heavy, contaminated fluid, it can be pumped using the pump module to attempt to clean the zone up. The tool can then be unset and moved on to a new zone of interest.

The device can be run in conventional, multi-lateral and other non-conventional or extended reach development wells. In horizontal wells, the tool can be set at several places in a horizontal section to flow up the coiled tubing in order to evaluate the well productivity. Alternatively, the well can be flowed up the tubing and the tool can monitor pressure, temperature and fluid type at locations along the horizontal section. In multi-lateral wells, each wellbore can be entered and specific zones can be evaluated separately before they are completed.

Fluid need not be brought to the surface. It can be reinjected into the test zone after the test, either from surface or with the pump module. The volume of fluid flowed can be measured via the number of pump strokes, which have a known volume. Hence the fluid level in the coiled tubing can be calculated at any time to avoid flowing to surface, if this is not required.

If flow to surface is desired, the downhole valve system within the tool and the valves in the choke manifold can act as a double barrier to shut in between the reservoir and the surface. It is also possible to sever the coiled tubing upstream of the tubing reel using the shear rams in the coiled tubing BOP (Blow Out Preventer) or the shear rams in the drilling BOP. The risks and possible consequences that could arise from operations with the improved downhole tool require a detailed safety review which takes into account the prevailing well control system on a rig.

The same surface fluid processing equipment is required as for a DST. Preferably, the pipework, choke manifold, heater, separator, gauge/storage tanks and flares are all of reduced size. Typically, flowrates will be less than for a typical DST since the coiled tubing internal diameter will generally be less than that of a typical DST tubing.

- 9 -

There are several advantages to being able to flow to surface. It will enable much greater, and in principle unlimited volumes to be produced. There can be much greater cleanup before samples are taken. The contents of the coiled tubing can be reverse circulated out (rather than just re-injected) after each sampling job. The greater offtake will also create a reservoir pressure disturbance which reaches further away from the wellbore. This is more valuable for reservoir characterisation using pressure transient analysis interpretation based on the pressure drawdown and pressure buildup cycle. The volume of offtake is essentially limited only by the time allocated for the task and the pump rate.

The downhole tool system can be run in oil or gas wells on land, offshore on fixed installations such as platforms or jackup rigs and on floating vessels such as drillships or semi-submersible rigs. A floating situation will require a heave compensation system and a subsea injector or other means to achieve a pressure seal around the coiled tubing within the rigs BOP (blow out preventer) which is set on the seabed. In a similar way to a DST, such means can provide the method to achieve pressure connection with the annulus and enable use of the standard rig kill and choke lines to the BOP for this purpose. A subsea coiled tubing BOP will also be needed to enable an emergency disconnection by severing the coiled tubing. This will cause the valve downhole to shut, isolating the coiled tubing, and surface, from reservoir pressure.

The present invention also provides a method for the evaluation of a well. The downhole tool of the present invention may be used alone or in combination with known downhole tools and/or methods of well evaluation. The improved downhole tool and method enhance the gathering of dynamic reservoir data. Dynamic reservoir data are acquired while reservoir pressures are changing and reservoir fluids may be flowing as a consequence. Examples of dynamic reservoir data are pressure and temperature drawdown and buildup as a consequence of fluid offtake and shut-in. Another example is the taking of fluid samples which requires the offtake of fluids from the reservoir. Static reservoir data by comparison include porosity, permeability, water saturation; also

pressures and temperatures measured when no fluids are flowing or when pressure differentials (which may or may not cause measurable fluid movement) have dissipated.

The improved downhole tool is best placed at the centre  
5 of the dynamic data acquisition planning. The nearest  
equivalent tools in use today, the WFS tools, are not typically  
used in this way. The approach of the present invention can  
lead to large departures from the usual sequence of events in  
conventional data acquisition. Examples might include running  
10 the tool before penetrating the whole reservoir or running the  
tool days before conventional open hole logs are run.

Placing the downhole tool of the present invention at the  
centre of dynamic data acquisition planning can create  
conflicts with other aspects of well drilling and data  
15 acquisition. These must be considered and resolved at the well  
planning stage to avoid compromising the use of the improved  
downhole tool.

Drilling mud cools the drill bit, lubricates the  
drillstring in the wellbore and transports the rock cuttings to  
20 surface in suspension. A mud which is optimal from a drilling  
or environmental viewpoint may not be suitable from a  
contamination of representative fluid samples viewpoint.

Open hole logs, which gather static reservoir data, are  
almost invariably run before a WFS. The improved downhole tool  
25 of the present invention may be run before or after open hole  
logs. The chosen sequence of data acquisition will reflect the  
well objectives and the data acquisition objectives. There are  
occasions where the need for dynamic data is more urgent than  
the need for static data, so the improved downhole tool of the  
30 present invention can be run first.

The present invention can strongly influence real-time  
decisions on a well. Resistivity, porosity and gamma ray data  
are all examples of measurements made with open hole logs.  
Several logs are needed and they require interpreting to  
35 indicate for example, the shale-corrected porosity and the  
water saturation. Traditionally these data, possibly combined  
with WFS data, are used to make a decision on whether or not to  
run a DST on a well. The improved downhole tool provides more  
direct measurements and therefore makes such welltesting

decisions simpler - to prove that reservoir fluids will flow, to sample them, to capture them in sample bottles and to allow surface inspection of samples.

The improved downhole tool may provide all the dynamic well evaluation which is needed. Or, it may indicate the remaining areas of uncertainty and help focus on specific aspects to evaluate further. It can thus help design a DST or other test which is optimised to gather this data.

There are some exploration wells which find hydrocarbons but are not worth testing. In such cases, careful planning and use of the improved downhole tool can provide hard data to facilitate making a "no test" decision quickly.

The improved downhole tool might indicate that representative fluid properties differ somewhat from one productive horizon to the next. This might be a case where prolonged testing and sampling was consequently planned on the same well to establish whether or not there really were fluid property differences.

The improved fluid sampler can be used to provide evidence of pressure depletion due to fluid offtake. The fluid offtake can be from the subject well or in the form of an interference test by fluids being produced from another well. In such a case, the improved downhole tool data would indicate whether a DST, or indeed a longer extended welltest might be required on the same well to investigate further the possibility of depletion.

The information obtained from the improved fluid sampler might indicate unexpectedly low productivity from a tested zone. This might indicate the merit of a maximum rate DST across the whole productive interval to confirm or refute the possibility of poor productivity. It might also give early warning to plan for a stimulation treatment. These are not always possible immediately after a disappointing DST due to significant planning, equipment and material lead times.

The method for best use of the improved downhole tool will produce different outcomes each time depending on the reservoir geology, well objectives, drilling programme, fluid properties, reservoir pressure and temperature. The method requires consistent thinking ahead about the well evaluation

and the best way to achieve, or even improve on the stated objectives. It is much more flexible than just following a fixed programme and more powerful than just reacting to events.

The improved downhole tool system of the present invention provides good quality data quickly. The improved downhole tool and method provide a means to optimise the gathering of dynamic reservoir data. This may avoid the need to re-enter a well or avoid the need to drill another well to address unanswered questions. The tool and method can be applied in an exploration, appraisal or development well.

- 13 -

## CLAIMS

- 1) A downhole tool system which comprises a downhole tool connected for fluid communication to a continuous reel of tubing, drill pipe or conventional tubing via a pressure-tight connector for flowing fluids between the formation, the tool and the surface, the downhole tool being in electrical communication with the surface.
- 2) A downhole tool system according to claim 1 wherein, by use of a pressure-tight connector, downhole fluids can be pumped through the tool, safely to surface and/or surface fluids can be pumped safely downhole via the continuous reel of tubing.
- 3) A downhole tool system according to claim 1 or 2 wherein the fluid being pumped can flow through the tool, exiting or entering at the top via the pressure-tight connector.
- 4) A downhole tool system according to claim 1 or claim 2 or claim 3 wherein the continuous reel of tubing, which might be coiled tubing, contains an armoured electrical wireline cable or has such a cable for electrical connection bonded to it or otherwise associated with it.
- 5) A downhole tool system according to claim 4 wherein power, control and data telemetry signals are transmitted between the downhole tool and the surface equipment via the electrical wireline cable.
- 6) A downhole tool system according to any one of the preceding claims wherein the tool is assembled from modules having different functions.
- 7) A downhole tool system according to claim 6 comprising at least one of a probe, single packer or straddle packer module, internally carried sample bottles, a large sample container, a pump module and modules containing various downhole sensors.
- 8) A downhole tool system according to any one of the preceding claims which is capable of providing real-time surface readout of pressure, temperature and differentiation of fluid phases.

- 14 -

9) A downhole tool system according to any one of the preceding claims which is capable of obtaining high quality downhole fluid samples; by flowing sufficient volume to clean up before representative samples can be taken; by providing  
5 real time indications of sample quality before and during sampling; and by capturing the samples under pressure, while downhole, in sample bottles which are certified for air transport.

10) A method of using a downhole tool system for well  
10 evaluation and intervention which comprises a downhole tool connected for fluid communication to a continuous reel of tubing via a pressure-tight connector for flowing fluids between the formation, the tool and the surface, the downhole tool being in electrical communication with the surface.

15 11) A method of using a downhole tool system to provide dynamic reservoir data to assist in the design of subsequent drill stem tests, stimulation, extended welltests or similar, by providing pressure information, productivity information and fluid composition information at the wellsite which enables  
20 welltest objectives to be confirmed or modified within a few hours or days of the testing being commenced.

12) A method according to claim 10 or 11 using a downhole tool system according to any one of claims 1 to 9.

25 13) A method according to claim 10, 11 or 12 run in either a cased hole or in open hole.

14) A method according to any one of claims 10 to 13 which comprises the use of downhole cameras, steering and traction devices.

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Fig.1.

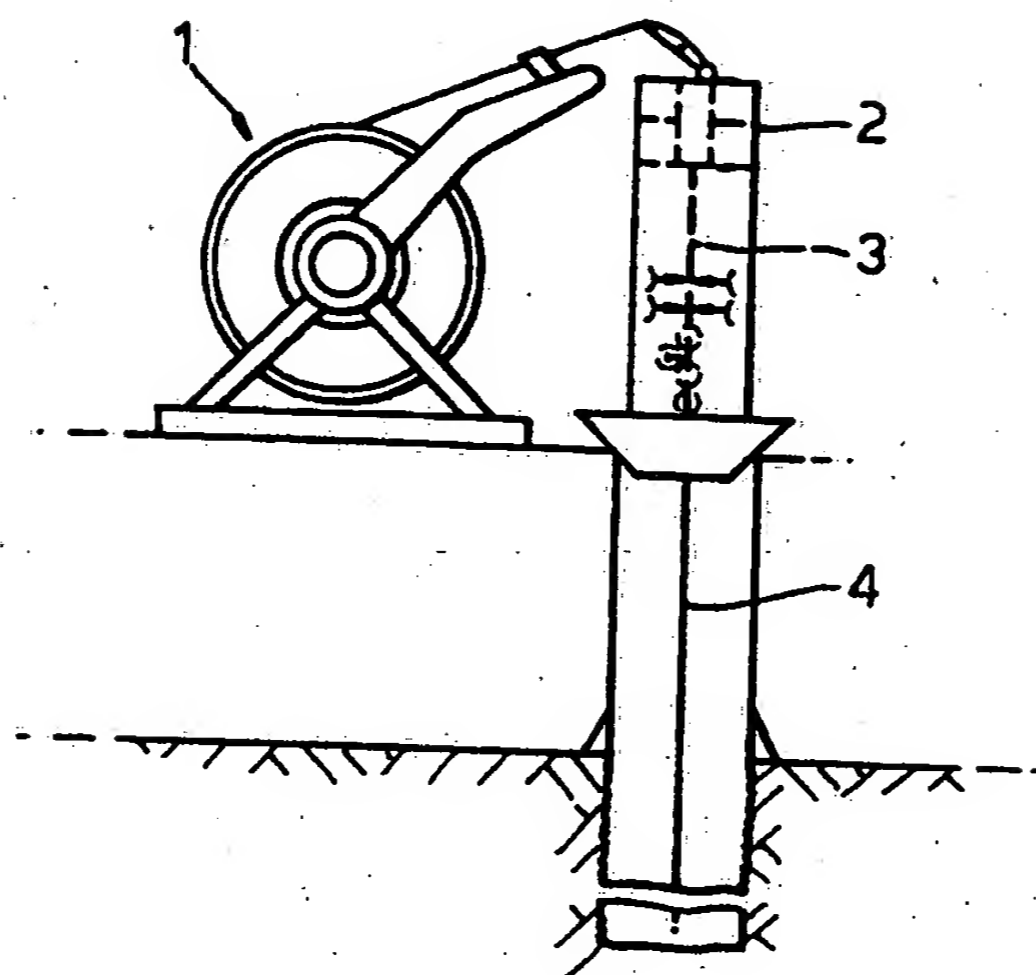


Fig.3.

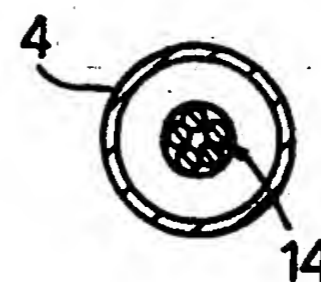
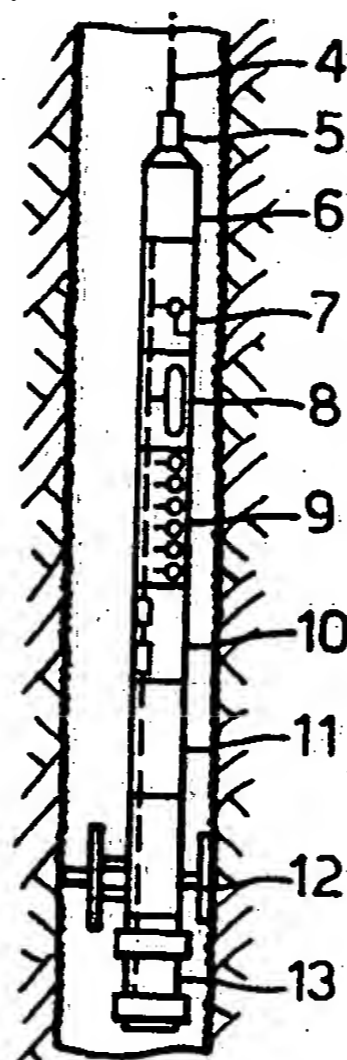


Fig.2.



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 96/02075

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 E21B17/20 E21B49/08 E21B49/10 E21B49/00 E21B47/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,5 351 533 (MACADAM JAMES M ET AL) 4 October 1994 see column 1, line 35-40 see column 2, line 46 - column 3, line 68 see column 5, line 28-33 see column 6, line 9-16	1-7,10
Y	---	8,9, 11-14
X	US,A,5 291 947 (STRACKE MARK L) 8 March 1994 see column 1, line 60 - column 2, line 36	1,3-6
X	US,A,5 337 838 (SORENSEN KURT I) 16 August 1994 see abstract see column 6, line 40-65 ---	1-5
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Date of the actual completion of the international search

10 December 1996

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# INTERNATIONAL SEARCH REPORT

International Application No.  
PCT/GB 96/02075

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Y	US,A,5 377 755 (MICHAELS JOHN M ET AL) 3 January 1995 see column 4, line 34-44 see column 5, line 66 - column 6, line 5 ---	9
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